Semi-annual Report
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## Abstract

Our major achievements of the past six months were: (i) final delivery of the cloud optical depth (MOD_PR06OD) and level-3 atmosphere tile (MOD_PR08T), daily (MOD_PR08D), and monthly (MOD_PR08M) algorithms, and (ii) participation and early analysis of MAS and CAR data from the FIRE III Arctic Cloud Experiment, conducted in Fairbanks and Barrow, Alaska, during May and June.

## I. Task Objectives

With the use of related airborne instrumentation, such as the MODIS Airborne Simulator (MAS) and Cloud Absorption Radiometer (CAR), our primary objective is to extend and expand algorithms for retrieving the optical thickness and effective radius of clouds from radiation measurements to be obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS). The secondary objective is to obtain an enhanced knowledge of surface angular and spectral properties that can be inferred from airborne directional radiance measurements.

## II. Work Accomplished

### *a. MODIS-related Algorithm Study*

The visible/near-IR thermodynamic phase algorithm (post-launch) is under development. The algorithm is expected to determine whether a cloud is made up of ice or liquid water by comparing ratios of reflectances at several wavelengths as functions of solar zenith angle, viewing polar angle, relative azimuthal angle, cloud optical depth, and effective particle diameter. Work is continuing to adapt sections of the level-2 code so that all needed reflectances can be interpolated from the ice/water cloud libraries, with appropriate corrections for Rayleigh scattering in the 0.66 μm channel and emission in the 3.7 μm channel. After a thorough theoretical study of ice/water cloud reflectances, an operational algorithm will be developed and tested using MODIS Airborne Simulator (MAS) data flown aboard an ER-2 research aircraft.

In parallel with the effort to make the final delivery of the MOD_PR06OD code, the latest MODIS spectral response functions (SRFs) were compared with previous versions obtained in 1996. In general, the MODIS SRFs shifted slightly, with band 1 in particular becoming more asymmetric. Peter Soulen and Steve Platnick recalculated the liquid water cloud libraries using routines provided by Prof. Teruyuki Nakajima (Nakajima and Tanaka, 1988; Nakajima and King, 1992). The ice cloud libraries will be recalculated as soon as Professor Kuo-Nan Liou's research group at UCLA completes calculating the ice cloud phase functions with the new MODIS SRFs. To double-check the retrieval libraries, a separate code based on the DISORT-routines of Stamnes et al. (1988) is being developed.

Development was completed for performing space-time aggregation of MODIS atmosphere products, i.e., codes to produce Level-3 daily gridded files from a collection of Level-2 granules. These codes will be used to aggregate all products (e.g., aerosol over land and ocean, water vapor, clouds, and ozone amount, etc.) in the Atmosphere Group. Although the computation of aggregate quantities (i.e., mean and standard deviation) on a regular grid is a relatively simple task conceptually, the mechanics of writing general, maintainable codes has proven to be quite involved. Roughly 10% of the codes perform the computations; the rest is devoted to bookkeeping, I/O, etc. We chose to implement the aggregation codes in Fortran 90, which has allowed us to make use of the language's extensive facilities for array processing and a variety of object-oriented features. These codes are designed to be both flexible and easy to modify. It makes extensive use of the self-documenting nature of the HDF files in which MODIS data are stored. This component of our task was performed by Robert Pincus, Paul Hubanks, and Xu Liang, two of whom are leaving Goddard to accept faculty positions at Universities (Pincus and Liang).

*b. MODIS code delivery*

MOD06 level-2 cloud retrieval code

Jason Li made an updated delivery of the MOD06 ancillary data package (used by MOD06) on February 18, 1998. Significant improvements to the code were subsequently made after testing, with input from Rich Hucek and Ran Song. The improved version was delivered on April 7. The ancillary package now (i) incorporates Liam Gumley's new NCEP reader; (ii) has new DAO readers to reflect the changes in the DAO file specifications; and (iii) fixes a fringe data point problem that occurred when assigning ancillary data to 1km level-1B pixels used by MOD06.

Ran Song delivered the final version of the PR_MOD06OD cloud retrieval code on June 30, 1998. Mark Gray has since been working with Rich Hucek on FORCHECK, highlighted and resolving the few remaining problems in the source code.

MOD08 level-3 atmosphere code

The level-3 atmospheres zonal tiling code PR_MOD08T, delivered to SDST in November 1997, was baselined by the DAAC in May 1998. SDST identified several minor flaws in the code, including inadequate documentation and some small memory leaks. After several short iteration cycles, the code was certified and delivered to the DAAC for integration and testing. Though the code still lacks the operator actions requested by the DAAC for each error message, SDST agreed to add these to the level-3 code as was done for the level-2 code.

The codes to create global files of daily (PR_MOD08D) and monthly (PR_MOD08M) level-3 atmosphere products from the zonal tiles were delivered to SDST in February 1998. These codes are much simpler than the zonal tiling code, and will require little in the way of testing.

*c. MODIS-related Instrumental Research*

*Cloud Absorption Radiometer (CAR) deployment improvements*

In conjunction with the University of Washington CV-580, and in time for the FIRE-Arctic Cloud Experiment (FIRE-ACE) in May and June, improvements were made to the Cloud Absorption Radiometer (CAR) in-flight capability and quick look data processing, including:

(i) In-flight viewing mode selections: nadir, starboard, BRDF, and zenith viewing modes;

(ii) New CAR raw data format including real-time GPS navigation information;

(iii) Post-flight data analysis.

*CAR UV channel*

During vicarious calibration of the UV channel late last year, Peter Soulen discovered there was a manufacturing flaw in the UV filter: a spurious transmission at ~365 nm. The defective filter was replaced with one of three new UV filters that transmit light at 380 nm with a bandwidth of 5 nm. Soulen measured the transmission of these new filters and found them to have only a 15% transmittance, substantially less than the 60% that was requested. However, in spite of this low filter transmission and the less-than-optimal behavior of the two dichroics in the UV optical path of the CAR, we are optimistic that the signal obtained by the CAR-UV channel during the FIRE-Arctic Cloud Experiment (FIRE-ACE) in May and June will still be roughly as strong as the signal from the defective UV filter. Preliminary indications are that the CAR performed well with the new UV filter during the FIRE-ACE campaign. During FIRE-ACE, the CAR made measurements of bidirectional reflectances of several different surfaces under diffuse light, one measurement of sea ice under very clear conditions over SHEBA and many more around Barrow, and multiple measurements of bidirectional reflectance of various single-layer arctic stratus, altocumulus, and cirrus clouds.

*CAR characterization*

A thorough calibration and characterization of the CAR is planned for later this summer by Tom Arnold and Peter Soulen. To determine if the CAR has a polarization sensitivity in any of its channels, we have ordered and received a 5.5-inch wide polarizer that is large enough to cover the CAR's entire field of view. If the new supporting equipment (monochromator, new brighter lamp source, etc.) are functional, we plan to make thorough determinations of stray-light errors, visible-light contamination of the UV-channel, and total spectral throughput of all channels up to 1.7 µm, as soon as the new supporting equipment is operational.

*CAR Data processing*

Tom Arnold has investigated the CAR offset (dark current value), which has led to several corrections to the data processing system. However, typically less than 1% of data for any of bands 1-7 are affected and at most a few percent of the data in bands 8-13 are affected. In the affected cases the error was only appreciable at very low radiance values.

*CAR BRDF processing*

Tom Arnold has processed all ARMCAS data from the Arctic in June 1995.

*d. Field Experiments*

*FIRE Arctic Cloud Experiment (FIRE-ACE)*

The FIRE-ACE experiment was held from mid-May through the first week of June, and included the NASA ER-2, NCAR C-130, and the University of Washington CV-580 aircraft platforms. The ER-2 and C-130 flew out of Fairbanks, AK while the CV-580 flew out of Barrow, AK. Primary science objectives included (i) comparison of spectral properties of sea ice and cloud layers, (ii) validation of satellite and airborne retrieval algorithms, (iii) testing of AMSR algorithm for distinguishing first year, multi-year and fast ice using microwave radiometers, (iv) validation of the MODIS cloud mask algorithm for distinguishing clouds from snow and sea ice surfaces in polar regions, (v) testing of MODIS cloud retrieval algorithms over sea ice surfaces during summer daytime conditions, (vi) determining radiative energy budget of clouds and sea ice in polar regions, (vii) comparison of satellite and ground based observations of clouds and clear sky in polar regions, and (viii) observational support for the SHEBA ice camp and the DOE ARM remote sensing sites.

MODIS Airborne Simulator (MAS) objectives included validation of the MODIS cloud mask algorithm for distinguishing clouds from snow and sea ice surfaces in polar regions (using a variety of solar and IR tests); testing of MODIS cloud retrieval algorithms over sea ice surfaces during summer daytime conditions (relying heavily on the 0.86, 1.6, 2.1, and 3.7 µm MAS bands); comparing satellite and ground based-observations of clouds and clear sky in polar regions; comparing SHEBA and ARM long-term, ground-based remote sensing sites; providing high spatial resolution imagery in support of other platform instruments. MAS was supported in the field by Tom Arnold, Ran Song, Suzie Young, and Tami Beitzel. Michael King and Steve Platnick served as ER-2 flight scientists.

All MAS flights were processed within about 3 days of flight at NASA GSFC. Level 1B data will be sent to the Langley Research Center DAAC for archival and distribution. Initial processing was performed with a preliminary pre-flight calibration. Users should be aware that post-flight and field calibration work may result in the reprocessing of the initial FIRE ACE data sets.

Coordination with in situ aircraft measurements is important for validation of MAS cloud microphysical retrievals. During the ER-2 mission, there were 5 coordinated flights with the University of Washington CV-580 (May 20, 29; June 2, 3, 6) and 3 coordinations with the NCAR C-130Q (May 18, 20, 27). A variety of atmospheric conditions were observed during these missions including clear sky, broken low cloud, uniform stratus decks, and multi-layer clouds and cirrus. Cloudy scenes were observed over tundra, open water to the southwest of Point Barrow, and sea ice of various types, structure, and age.

Initial MAS imagery demonstrate the strong and often confusing effect of an underlying bright sea ice surface on cloud reflectance in the visible MAS channels. This is in contrast to the corresponding dark reflectance of ice surfaces in the 1.6, 2.1, and 3.7 μm bands used by our cloud retrieval algorithms. Comparisons with AMPR have allowed several complicated scenes in the MAS imagery to be interpreted as the effect of a surface transition between sea ice and open water.

MAS documentation, ordering information, experimental data (including browse imagery for each flight), ER-2 flight tracks and mission summaries can be found at the following web page set up by Paul Hubanks: http://ltpwww.gsfc.nasa.gov/MAS/fireacehome.html. A summary report from all ER-2 instrument teams can be found on the FIRE-ACE web page at http://eosweb.larc.nasa.gov/ACEDOCS/data/endof_er2_summary/er2b.html.

The CAR was deployed on the University of Washington CV-580 and flown out of Barrow, Alaska from mid-May to June 7 in support of FIRE-ACE. Jason Li, Tami Beitzel, Suzie Young, Michael King, and Mark Gray flew on the CV-580, operating both the CAR and SSFR (solar spectral flux radiometer) instruments during flight. At the end of the FIRE experiment, the CV-580 continued to fly for an additional two weeks with the CAR and SSFR for support of radiation measurements over and near the SHEBA ice camp. Peter Soulen manned the CAR during this time. A web site for CAR FIRE-ACE was developed by Jason Li, Suzie Young, and Tami Beitzel; the URL is: http://climate.gsfc.nasa.gov/~jyli/Car/data/fire3.

A FIRE-ACE field mission summary report was compiled by Tami Beitzel and

Suzie Young. It as well as the CAR report are available via ftp at macx.gsfc.nasa.gov (user `guest`, password `macx`). It is in the folder `pub`.

*e. MODIS-related Services*

*Meetings*

1. MODIS Atmosphere Discipline Group Meeting, St. Michaels, MD, 3-5 February 1998. Attended by T. Arnold, M. Gray, M. D. King, J. Li, X. Liang, S. Platnick, R. Pincus, R. Song, P. Soulen, S. C. Tsay.

2. Si-Chee Tsay attended the Department of Energy Atmospheric Radiation Measurement (ARM) meeting in Tucson, AZ, on 4-6 March 1998, where he presented a poster on bidirectional reflectance measurements made by the CAR in Brazil.

3. Steve Platnick attended the EOS PM-1 Validation Workshop, College Park, MD, 1-2 April 1998.

4. Michael King attended the Science Working Group for the AM Platform Meeting, King of Prussia, PA, 2 April 1998.

5. Steve Platnick attended the MODIS Calibration Meeting, Greenbelt, MD, 23 June 1998.

6. MODIS Science Team meeting and Atmosphere Discipline Group Meetings, Greenbelt, MD, 24-26 June 1998. Attended by M. Gray, P Hubanks, M. D. King, J. Li, X. Liang, S. Platnick, P. Soulen, S. C. Tsay.

7. Steve Platnick and Michael King regularly attended weekly MODIS Technical Team meetings. Steve Platnick participated in MCST reflectance solar calibration issues, especially those effecting the SWIR bands (including analyzing the impact of the 2.5 and 5.3 μm light leakage problem, and $1^{st}$ and $2^{nd}$ sampling electronic problems).

8. Attended Science Executive Committee meetings in Chicago on 5 January and 29 April.

*Seminars*

1. King, M. D., “Clouds, Radiation, and Climate from the Earth Observing System,” and “Site Visit to US Antarctic Facilities” at Colorado College, Colorado College, CO (January).

2. King, M. D., “Earth Observing System: Science Objectives and Challenges” at NASA Dryden Flight Research Center, Edwards, CA, and “Remote Sensing of Cloud, Aerosol, and Water Vapor Properties from MODIS” at UCLA, Los Angeles, CA, (February).

3. King, M. D., “Earth Observing System: Science Objectives and Challenges” at National Space Program Office, Taiwan (April).

## III. Data/Analysis/Interpretation

### *a. Data Processing*

All eleven MAS flights obtained during FIRE-ACE have been processed to level-1B (calibrated and geolocated radiances) using preliminary (preflight) radiometric and spectral calibration. In addition, browse images and flight tracks were made accessible via World Wide Web (http://ltpwww.gsfc.nasa.gov/MAS) within 3 days of acquisition throughout the experiment.

Figure 1 shows a composite of MAS imagery constructed from the Arctic Cloud Experiment.

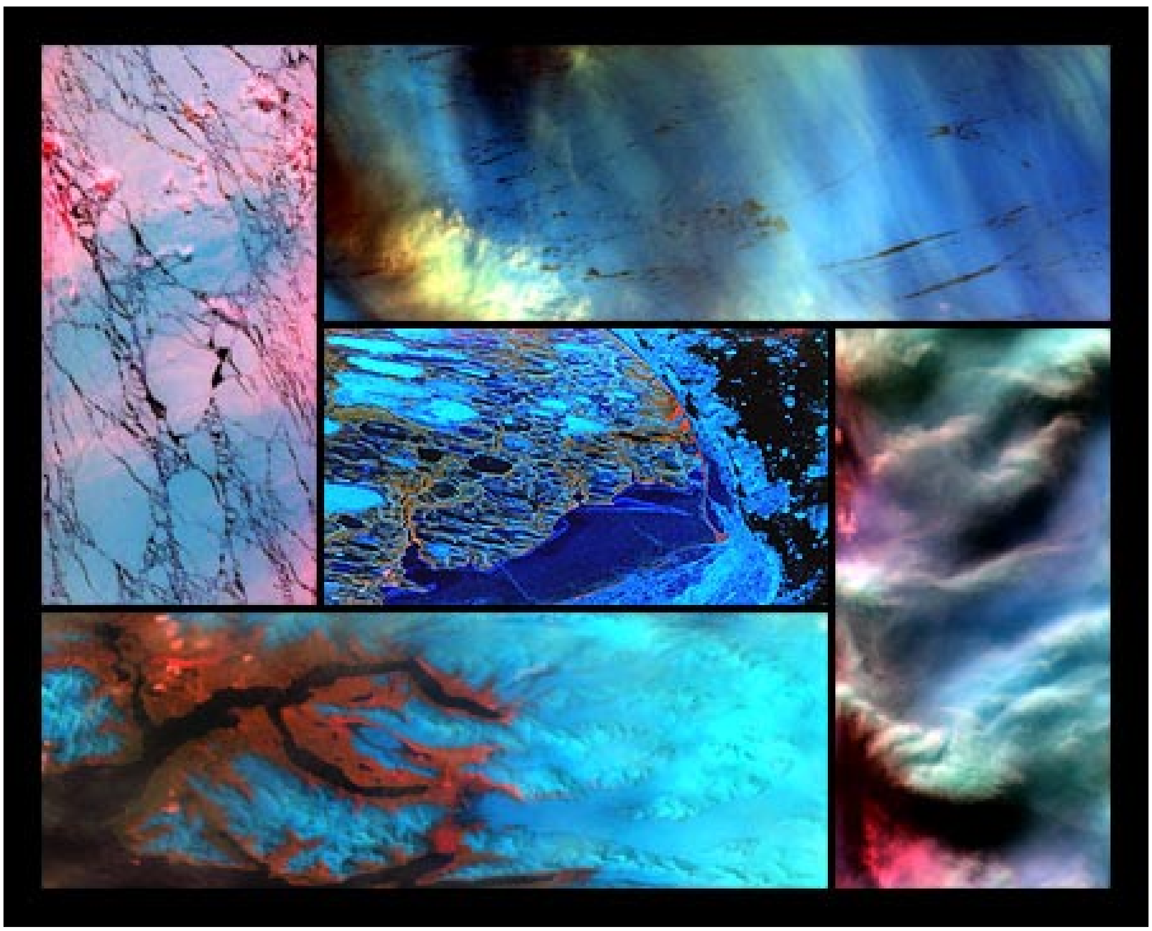

Figure 1. Clockwise from the upper left (center last) the images depict: (a) Large broken ice sheets surrounding the SHEBA ice station, (b) Cirrus cloud streaks over broken sea ice, (c) Multilayer clouds and shadows over the Brooks Range, (d) Thin cirrus over glaciers in the Saint Elias Mountains, (e) Fast ice and open water surrounds Point Barrow and the tundra near the DoE ARM site.

*b. Analysis and Interpretation*

Retrieving cloud properties over highly reflecting surfaces is not a trivial task, since the multiple reflection between cloud and surface increases the system reflectance at all non-absorbing channels. This in turn reduces the sensitivity on retrieving cloud properties or increases the possibility of getting multi-valued solutions. The ACE measurements were designed to acquire data for testing our cloud retrieval algorithm over highly reflecting surfaces. An example of test results is discussed below. Figure 2 shows the time and location of ER-2 measurements on 20 May 1998, during which the ER-2 was initially coordinated with repeated underflights by the University of Washington CV-580 aircraft over the DoE ARM site in Barrow. The cloud fields along the CV-580 portion of this flight consisted of relatively uniform and single-layered stratus clouds over the tundra, breaking stratocumulus over Barrow, and clear sea ice off shore in the Beaufort Sea (also identified clearly from Cloud Lidar System data, not shown).

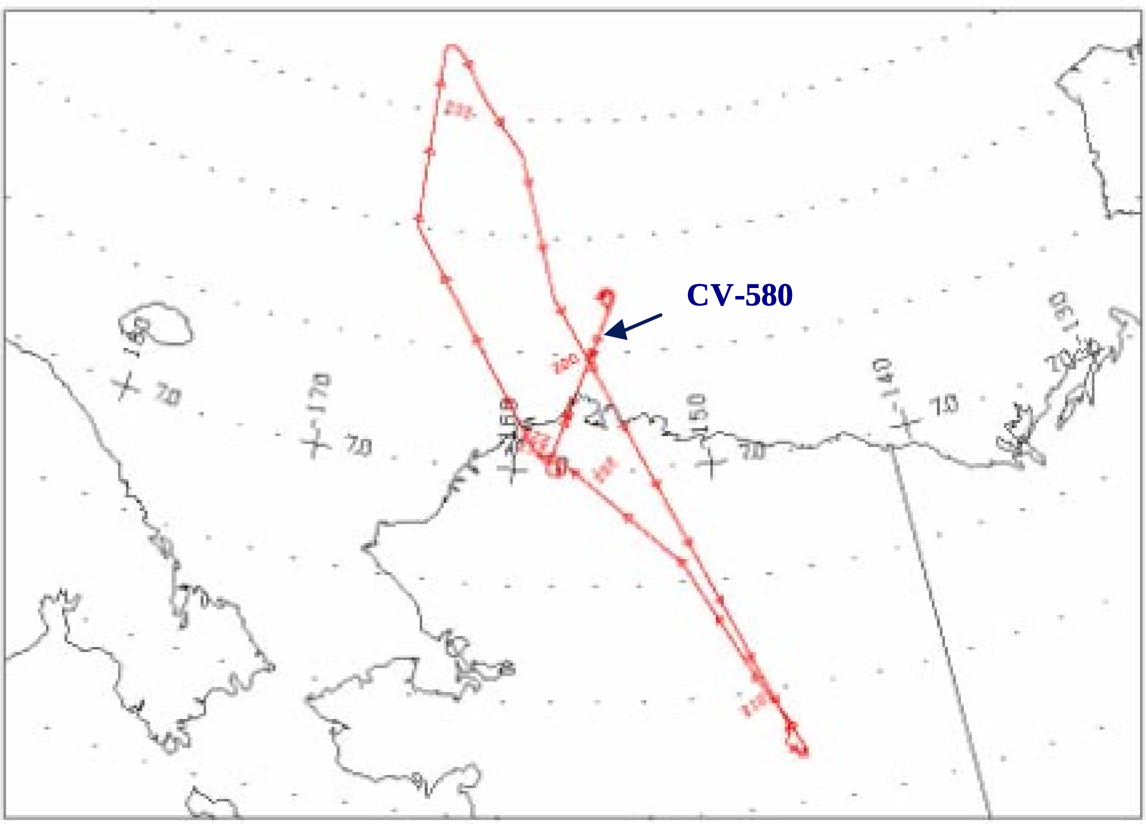


Figure 2. ER-2 ground track on 20 May 1998, with the first part of the flight track coordinated with underflights of the University of Washington CV-580 aircraft.

Figure 3 shows an MAS image of Arctic stratus clouds obtained over the tundra southwest of Barrow as the ER-2 flew in a north-northeast direction (heading of 23.5°). This image was constructed as a red-green-blue composite of 3 spectral bands (2.13, 1.62, and 0.55 μm) when the solar zenith angle $\theta_0$ = 54.3° and the sun was at an azimuth angle $\phi_0$ = 139.9°.

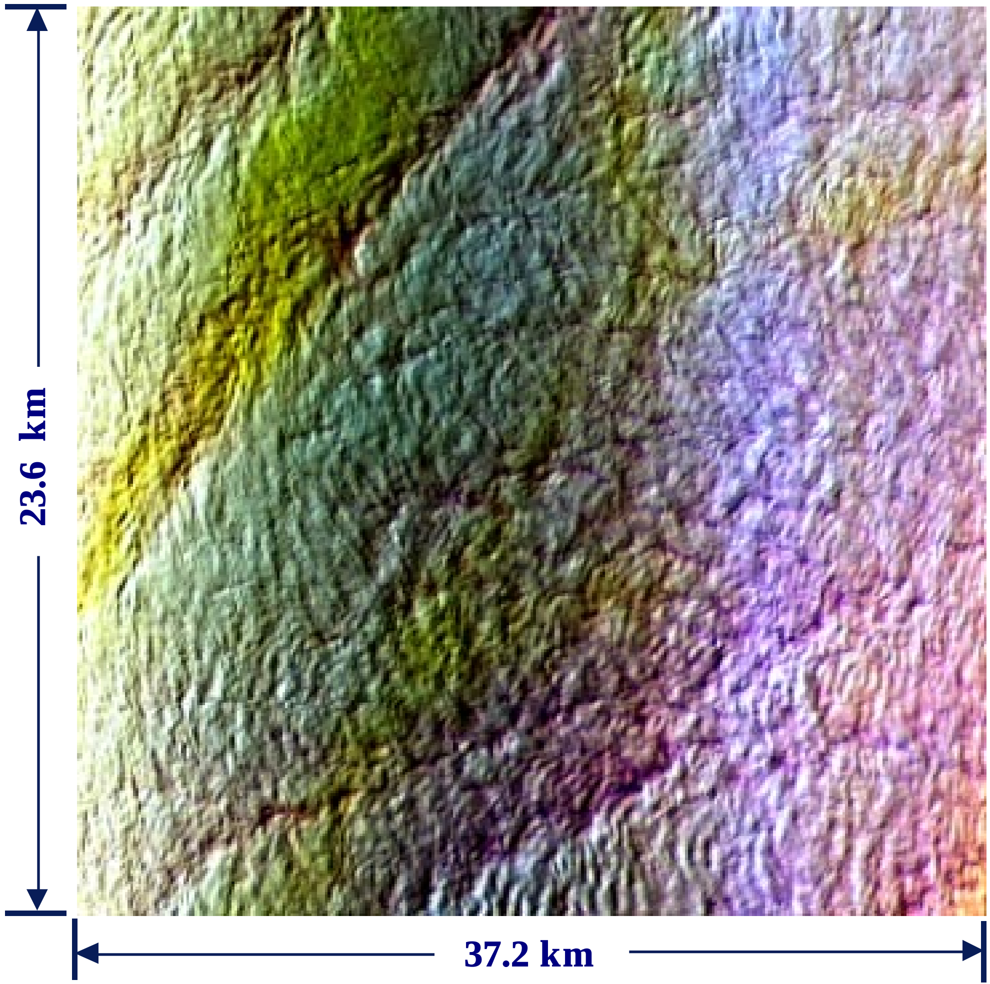


Figure 3. MAS image of Arctic stratus clouds over the tundra near Barrow, obtained at 2011 UTC on 20 May 1998 (70°25′N, 157°31′W) when the ER-2 was heading north-northeast at 23.5°. The image was constructed from 2.13, 1.62, and 0.55 μm bands as a red-green-blue composite. The ER-2 was heading from top to bottom down the centerline of the image.

MAS data from the entire flight light were first run through the MAS version of the MODIS cloud mask (Ackerman et al. 1998), from which the cloudy pixels were analyzed for cloud optical thickness and effective radius using the operational MOD06OD code delivered to SDST. The retrieved results are presented in Figs. 4 (optical thickness) and 5 (effective radius). The cloud optical thickness retrieval is quite reasonable, and reflects primarily the Arctic stratus cloud layer shown in Figure 3. The large spike of low optical thickness values, however, is a byproduct of the cloud mask retrieval that incorrectly identified the clear sea ice part of the scene as cloudy. This is also reflected in the effective radius retrieval (Fig. 5), which showed both a well defined cloud droplet probability density function and a narrow (erroneous) retrieval from the clear sea ice being misidentified as cloud.

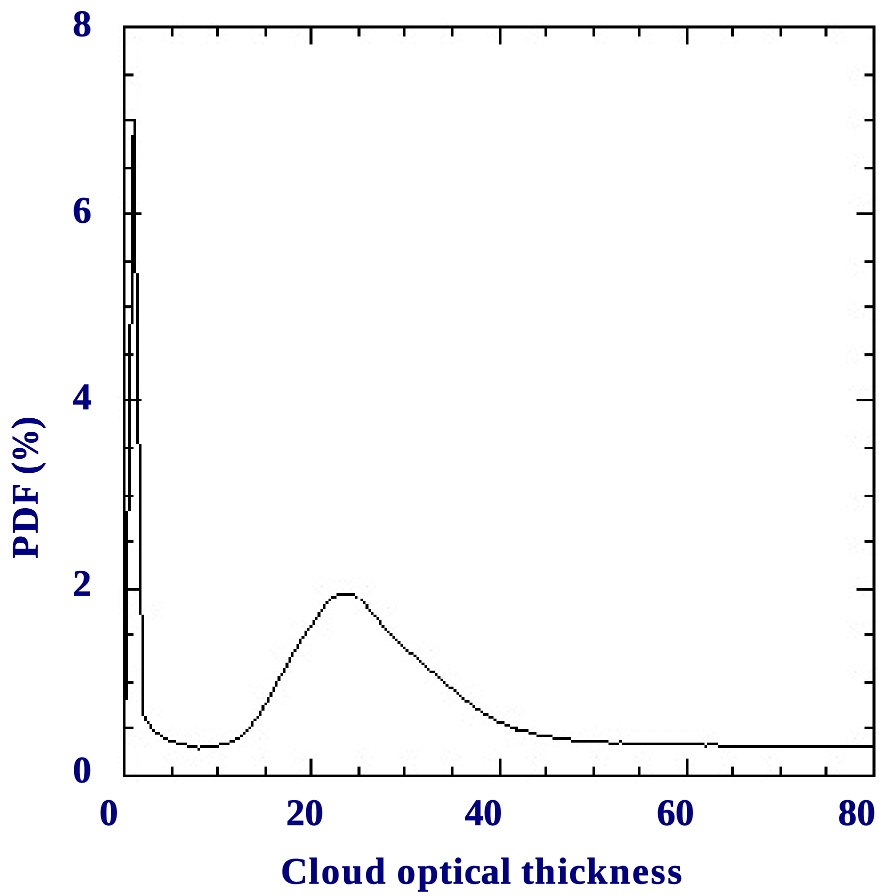


Figure 4. Marginal probability density function of cloud optical thickness for a 285 km flight line over the tundra, Barrow, and offshore first-year ice on 20 May 1998. The primary mode of cloud optical thickness (mode $\tau_c = 23$) occurred over the Arctic stratus overlying tundra, illustrated in Fig. 3.

Subsequent to this result, obtained within a couple of days of acquisition in Alaska, Steve Ackerman identified the problem with the cloud mask and reran the code, this time eliminating these false retrievals. This is a clear example of how rapid response to data processing and prototyping in the field, prior to launch of AM-1, is being used to improve the accuracy of the MODIS-delivered algorithms.

**IV. Anticipated Future Actions**

a. Continue to test and refine our delivered MODIS *v2* cloud retrieval algorithm;

b. Continue to analyze MAS, AVIRIS, and CLS data gathered during the ARMCAS and ACE campaigns, as well as University of Washington C-131A (and CV-580) in situ data, all with the express purpose of helping to improve the MODIS cloud masking algorithm;

c. Continue to analyze surface bidirectional reflectance measurements obtained by the CAR during the Kuwait Oil Fire, LEADEX, ASTEX, SCAR-A

ARMCAS, SCAR-B, TARFOX, and FIRE ACE experiments;

d. Attend the MODIS Atmosphere Group Retreat (November 4-6), to be held at St. Michaels Harbour Inn, for MODIS products.

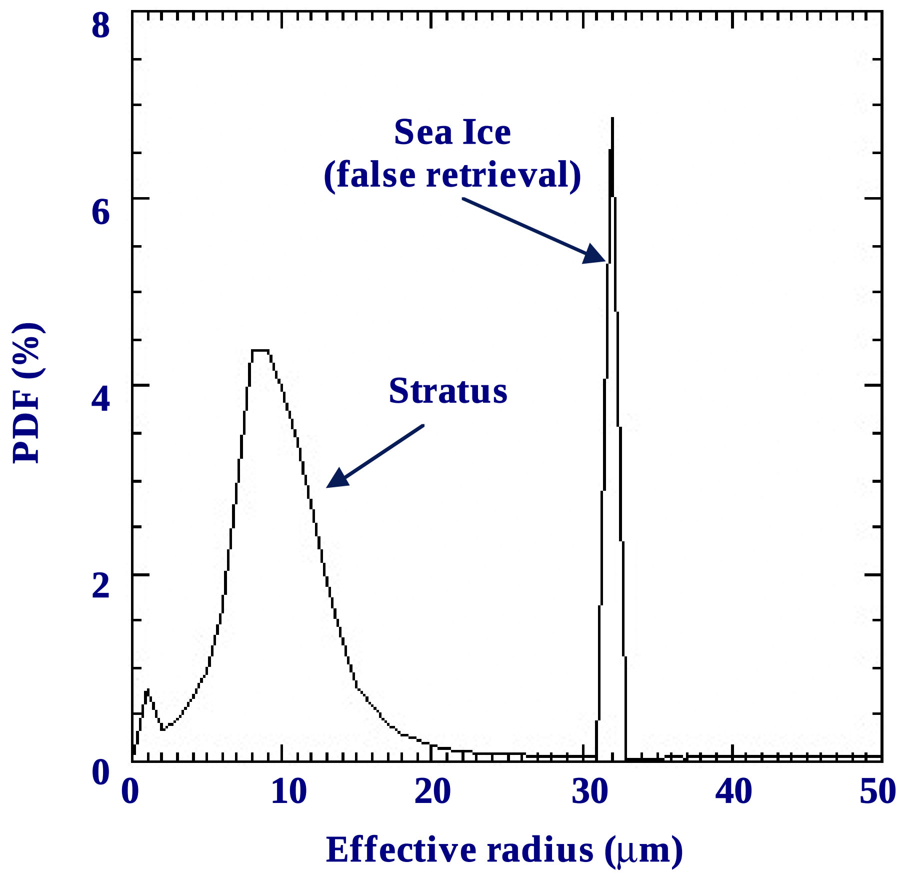


Figure 5. Marginal probability density function of effective for a 285 km flight line over the tundra, Barrow, and offshore first-year ice on 20 May 1998. The primary mode of effective (mode $r_e$ = 10 μm) occurred over the Arctic stratus overlying tundra, illustrated in Fig. 3, while the secondary spike at $r_e$ = 32 μm was a false retrieval due to incorrectly identifying clear sea ice as cloud.

## V. Problems/Corrective Actions

No problems that we are aware of at this time.

## VI. Publications


1. Ackerman, S. A., C. C. Moeller, K. I. Strabala, H. E. Gerber, L. E. Gumley, W. P. Menzel and S. C. Tsay, 1998: An infrared retrieval algorithm for determining the effective microphysical properties of clouds. *Geophys. Res. Lett.*, in press.

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Nakajima, T., and M. D. King, 1992: Asymptotic theory for optically thick layers: Application to the discrete ordinates method. *Appl. Opt*., **31**, 7669-7683.

Stamnes, K., S.-C. Tsay, W. Wiscombe, and K. Jayaweera, 1988: Numerically stable algorithm for discrete ordinate and matrix operator method radiative transfer. *Appl. Opt*., **27**, 2502-2509.